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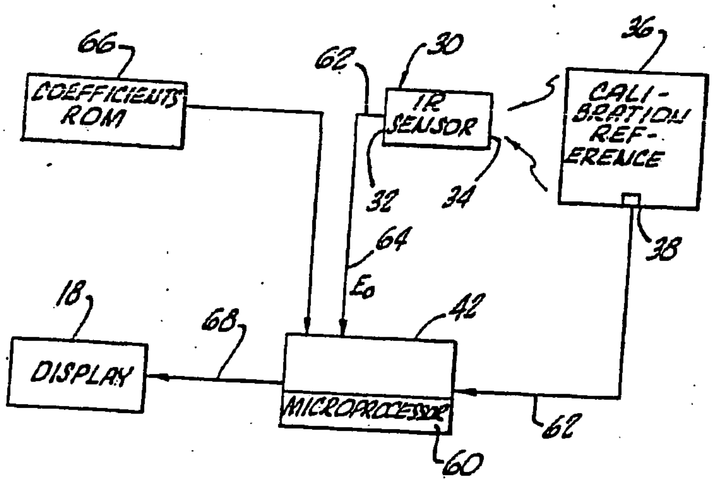

(57) Abstract

An infrared thermometer (10) determines the temperature of an object placed in front of the infrared sensor (30) of the thermometer. The sensor signal when looking at a reference object of a known temperature is compared to the sensor signal when looking at a target object of an unknown temperature, from which the target temperature is calculated. The target temperature cal-

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INFRARED THERMOMETER AND RELATED METHOD OF CALIBRATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to infrared thermometers and, more particularly, to calibration systems for such thermometers.

2. Description of the Related Art

Infrared thermometers have a number of desirable qualities, such as the ability to measure a person's body temperature in a fraction of a second and to provide readings without requiring the person to lie still for an extended time. In addition, such thermometers are generally easy to use and have a relatively low risk of infection in normal usage. These qualities make infrared thermometers especially popular in hospital and clinical settings, where they can be used to quickly and reliably determine the body temperatures of many patients under generally sanitary conditions.

Infrared thermometers use an infrared sensor, or a thermopile, that generates an electrical current signal that varies in accordance with the temperature of a target placed in front of the sensor. Such sensors have a cold junction and a hot junction. The hot junction is the portion of the sensor that is exposed to the target whose temperature is to be measured, while the cold junction is the portion of the sensor that is isolated from the target. The sensor signal indicates any difference between the temperature of the cold junction and the temperature of the target.

In the case of infrared thermometers adapted to measure a patient's body temperature, a probe is typically inserted into the patient's ear canal and directed toward the tympanic membrane, or eardrum, such that infrared radiation from the eardrum impinges on the hot junction of the sensor. The eardrum temperature, which is generally an accurate indication of the patient's body temperature, can then be calculated by adding the temperature difference indicated by the sensor output signal to the sensor's cold junction temperature.

Because the sensor output signal indicates the temperature difference between the cold junction and the target rather than the target's absolute temperature, the accuracy of the calculated temperature is affected by the accuracy with which the cold junction temperature is determined. Therefore, the cold junction must be maintained at a precisely controlled temperature, or the cold junction temperature must in some other way be accurately determined. It is usually more convenient to determine the temperature of the cold junction and provide temperature compensation than it is to maintain the cold junction at a controlled point. Various systems have been used for determining the temperature of the cold junction.

In some cold junction compensation systems, the cold junction is assumed to be at ambient temperature and a separate thermometer or an operator input is used to specify the ambient temperature. Such systems are not believed to be especially reliable or accurate. Other systems use a resistance measuring bridge circuit with a temperature-sensitive resistor, or thermistor, to precisely measure the temperature of the thermistor, which is assumed to be the temperature of the sensor. This temperature can then be used to directly compensate the infrared sensor output signal.

Many cold junction temperature compensation circuits are quite complicated and can add greatly to the cost of producing infrared thermometers. Other compensating systems do not provide a great deal of measurement accuracy, or are not especially reliable. Infrared thermometers are otherwise advantageous, especially in a clinical setting where the faster speed and less intrusive nature of infrared thermometers are desirable. Simpler cold junction compensation systems could reduce the cost of providing infrared thermometers, making their superior qualities more widely available, and could provide greater accuracy and improved reliability.

Another factor affecting the accuracy of infrared-based thermometers is that the gain of the infrared sensor changes as the temperature of the sensor changes. As a result of such gain changes, thermometer circuitry that might be accurate at a particular cold junction temperature might give erroneous readings at another temperature. For example, an infrared thermometer that provides an accurate measurement of body temperatures lying in a range of 88°F to 108°F when the sensor temperature is at 68°F might not be accurate over that same range when the sensor temperature is 78°F. Thus, even systems that reliably determine the temperature of the cold junction do not necessarily provide accurate measurements across a range of target temperatures if they do not compensate for temperature changes in the sensor itself.

From the discussion above, it should be apparent that there is a need for an infrared thermometer with a simple cold junction compensation circuit that provides greater accuracy and reliability of measured temperatures over a range of operating temperatures. The present invention satisfies this need.

SUMMARY OF THE INVENTION

The present invention is embodied in an infrared sensor-based thermometer that determines the temperature of a target and calibrates its temperature determination by determining the temperature of the sensor's cold junction based on the sensor's internal resistance, and by compensating for changes in the sensor's signal gain that occur with changes in its temperature. The calibration greatly increases the reliability and accuracy of the target temperature determination and also reduces the cost of the thermometer from what it would be using conventional systems to provide similar benefits. The sensor calibration function is achieved using many of the same circuit components also used for the temperature determination function, thereby not adding unduly to the complexity of the thermometer.

More particularly, a thermometer in accordance with the present invention includes a thermometer housing having a probe, within which is located the infrared sensor. The sensor is selectively positioned so that its hot junction receives infrared energy from a target whose temperature is to be measured, so that the sensor generates a target sensor signal, which indicates any difference between the target temperature and the cold junction temperature of the sensor. The thermometer also accurately determines the temperature of the sensor's cold junction by measuring the sensor's internal resistance, this cold junction temperature determination is used to determine the sensor's gain, so that the proper compensation coefficients can be applied to the calculation of target temperature. The thermometer then calculates the temperature of the target using the target sensor signal and the sensor gain value.

In an alternative embodiment, an enhanced calibration is provided using a calibration reference whose temperature is known by means of a thermistor. Before providing a calculation of target temperature, the probe containing the infrared sensor is selectively positioned so that the hot junction of the sensor receives infrared radiation from the calibration reference. At this time, the sensor produces a reference sensor signal that establishes a baseline signal value. Thereafter, when the temperature of a target is to be calculated, the calibration reference is moved out of the sensor's field of view and the sensor is then positioned such that its hot junction receives infrared radiation from the target, whereupon it produces a target sensor signal. Using a quadratic formula with inputs of the target sensor signal, the reference sensor signal, a sensor gain coefficient, and the sensor cold junction temperature, the temperature of the target is then calculated. The sensor gain coefficient is calculated using a linear gain formula that is a function of the sensor's cold junction temperature. The coefficients of the quadratic target temperature formula are empirically determined for each infrared sensor. The coefficients for the sensor gain function are likewise empirically determined for each infrared sensor.

The invention provides a quick and reliable means of determining the body temperatures of a large number of patients. Reading the calculated temperature does not require a great deal of skill or technique, but can be readily performed with a minimal amount of training. The invention provides a simplified sensor temperature compensation circuit to correct for changes in sensor gain with changes in sensor temperature.

Other features and advantages of the present invention should be apparent from the following description of the preferred embodiment, taken in

conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view of a thermometer apparatus in accordance with the present invention.

FIG. 2 is a simplified block diagram of the electrical components included in the thermometer of FIG. 1.

FIG. 3 is a graph showing the relationship between sensor resistance and sensor temperature for a typical infrared sensor of the type illustrated in FIG. 2.

FIG. 4 is a schematic diagram of a sensor circuit included in the infrared sensor thermometer illustrated in FIG. 1.

FIG. 5 is a schematic diagram representing the effective sensor circuit when the FIG. 4 circuit is in an amplifying mode.

FIG. 6 is a schematic diagram representing the effective sensor circuit when the FIG. 4 circuit is in a resistance measurement mode.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference now to the illustrative drawings, and particularly to FIG. 1, there is shown an infrared thermometer 10 that includes a generally pistol-shaped housing 12 with a handle portion 14 and an elongated probe 16 adapted for insertion into a patient's outer ear canal. A display 18 is mounted at the rear of the housing, for

displaying calculated temperatures, system messages, and functional indications. An infrared sensor 30 (FIG. 2) located within the probe receives infrared radiation from the patient's eardrum and generates a corresponding electrical signal that is processed to determine the patient's body temperature. Specifically, the patient's body temperature is determined by comparing the infrared sensor signal generated while the sensor receives infrared radiation from the patient's eardrum with the signal generated while the sensor receives infrared radiation from a calibration reference having a known temperature. The thermometer 10 also accurately determines the temperature of the sensor and compensates for signal changes that occur with changes in the temperature of the sensor.

Before being used to determine a patient's body temperature, the thermometer 10 first must be calibrated. An indexing handle 20 on the housing 12 slides rearwardly to place the thermometer in a calibration mode, and it slides forwardly to place the thermometer in a ready mode. In the calibration mode, the elongated probe 16 is retracted into the housing and the infrared sensor 30 (FIG. 2) is positioned to receive infrared radiation from a movable calibration reference 36 (FIG. 2). When the indexing handle 20 is moved forwardly to place the thermometer 10 in the ready mode, the calibration reference is moved away from the sensor and the elongated probe is moved out of the housing. The probe then may be inserted into the outer ear canal of a patient whose temperature is to be measured. A suitable mechanical structure for moving the probe relative to the calibration reference and housing is disclosed in U.S. Patent No. 4,993,424, which is incorporated herein by this reference.

In the ready mode, a trigger 22 may be depressed to activate the temperature measurement circuitry of the

thermometer, which includes a compensation system that accurately measures the internal resistance of the sensor, and therefore its temperature, and that also accounts for changes in the gain of the sensor due to its temperature. The measured patient's body temperature is then shown on the display 18.

FIG. 2 is a simplified schematic representation of an internal portion of the thermometer 10 illustrated in FIG. 1. It shows the thermometer's infrared sensor 30, which has a cold junction 32 and a hot junction 34, positioned adjacent to the movable calibration reference 36. When the thermometer is placed in the calibration mode, i.e., with the indexing handle 20 retracted rearwardly, the calibration reference 36 is moved directly in front of the retracted probe 16 so that the hot junction 34 of the sensor receives infrared radiation substantially only from the calibration reference. As a result, the sensor produces an electrical output signal that indicates the difference in temperature between the cold junction and the calibration reference. The temperature of the movable calibration reference 36 can be accurately determined using a thermistor 38, using techniques known to those skilled in the art.

When the thermometer 10 is in the calibration mode, tests are performed by the thermometer's circuitry to ensure that the infrared sensor 30 and other electronic components of the thermometer are in a stable condition and to ensure that the ambient temperature and thermometer component temperatures are relatively stable. If temperature changes or other thermometer conditions are detected to be changing beyond predetermined limits, the thermometer will condition itself not to allow measurements to be taken. Sensor stability can be checked by examining the output signal of the sensor when the sensor is exposed to the calibration reference 36.

When the sensor 30 is first positioned adjacent to the calibration reference, the hot junction 34 of the sensor receives infrared radiation from the reference and the sensor produces a sensor reference signal P_b that is indicative of the difference in temperature between the reference and the sensor cold junction 32. This sensor reference signal establishes a baseline for the remaining calculations. If the sensor reference signal P_b is determined to vary above a predetermined rate, then the calibration process is re-initiated and a temperature measurement cannot be taken until calibration is complete and a new sensor reference signal P_b is established. Between measurements, the probe 16 remains retracted within the housing 12 and the calibration sequence is performed at regular intervals, e.g., every 15 seconds, to continuously update the sensor reference signal P_b.

An advantageous feature of the thermometer 10 is that it saves the last baseline sensor reference signal value P_b before the indexing handle 20 was moved forward, because an operator might want to take a temperature measurement between calibration intervals without waiting for another calibration interval to be completed. Because during the calibration condition the thermometer calibrates every 15 seconds, the P_b value can be no older than 15 seconds, and any variance in the sensor temperature within the 15-second interval will ordinarily be so small that using the previous P_b value will not add unacceptable error into the calculation.

Because the output signal of the sensor indicates only the difference between the temperature of the sensor cold junction 32 and the temperature of the object from which it is receiving infrared radiation, it ordinarily is necessary to know the sensor's cold junction temperature, or at least a base approximation of that temperature, before an absolute object temperature can be

provided. Some conventional infrared sensor-based thermometers use a measurement of ambient temperature to approximate the sensor temperature, while others rely on an operator input value. The ambient temperature measurement, however, is not necessarily an accurate representation of the cold junction temperature, and an operator input is potentially even less accurate. The thermometer 10 in accordance with the present invention overcomes these deficiencies by providing an accurate indication of the sensor's cold junction temperature based on a calculation of the sensor's internal resistance. This is a more accurate and precise way of determining the base temperature as compared with conventional alternatives.

In accordance with the invention, the infrared sensor 30 is preliminarily tested to precisely determine the relationship between its cold junction temperature and its internal resistance. A chart of a typical relationship is shown in FIG. 3. After the temperature-resistance relationship has been determined, the internal resistance of the sensor 30 is advantageously determined at any temperature by establishing a bridge circuit that includes the sensor resistance and by passing a current through the sensor as part of the bridge circuit. A sensor offset signal P_s is produced by the sensor when a pulsed current is passed through the sensor circuit as the sensor is exposed to the calibration reference 36. Those skilled in the art will realize that the change in output voltage of the sensor for a given pulsed current can be used to determine the resistance of the sensor. The actual sensor temperature can be calculated from the change in output voltage by using the following quadratic sensor temperature formula:

$$T_s = C1\ (P_s - P_b)^2 + C2\ (P_s - P_b) + C3$$

where P_s is the sensor offset signal, P_b is the baseline sensor reference signal, and C1, C2, and C3 are constant coefficients that are empirically determined, as described further below.

After the temperature of the cold junction 32 of the infrared sensor 30 has been determined, a sensor gain factor must be determined before the temperature of a target can be calculated. It is important to determine the sensor gain because a sensor target signal P_t produced by the sensor when it is exposed to a target of unknown temperature can vary over a given range of sensor operating temperatures even for a target of fixed temperature. That is, although the sensor target signal provides an indication of the temperature difference between the cold junction and the target, the relationship between the sensor target signal and the indicated temperature difference, i.e., the gain of the sensor, can change with the temperature of the sensor.

It has been found that the gain function of the infrared sensor 30 can be approximated by the following linear gain formula:

$$G = K1 * T_s + K2$$

where T_s is the sensor temperature and K1 and K2 are constant coefficients that are empirically determined, as described further below.

After the sensor temperature and the gain factor have been determined, the temperature of the target, that is, the patient's body temperature, can be calculated. The temperature calculation is made by moving the elongated probe 16 out of the housing 12, placing the thermometer in the ready mode, and by inserting the probe into the patient's outer ear canal and depressing the

trigger 22. The temperature calculation is made by using the following temperature calculation formula:

$$T = ([(P_t - P_b)/G] + T_r^4)^{1/4}$$

where P_t is the sensor target signal from the infrared sensor 30, P_b is the baseline sensor reference signal, G is the sensor gain, and T_r is the reference target temperature provided by the thermistor 38. The calculated target temperature T is displayed on the display 18 while the trigger 22 is depressed, while afterwards the display shows the maximum calculated temperature during the time interval beginning when the elongated probe 16 was moved out of the housing 12 and ending when the trigger was released. The maximum calculated temperature is displayed until the probe is retracted. The temperature T calculated by the thermometer 10 has been found to be very accurate and reliable, allowing many temperatures to be quickly taken under generally sanitary conditions. The thermometer provides these benefits at reduced cost and with greater efficiency.

The thermometer circuitry advantageously uses many of the same electrical components both in determining the resistance of the sensor and in determining the temperature of the target, thereby providing cost savings. The operation of the thermometer circuitry, including the infrared sensor 30, is best understood with reference to the schematic diagram of FIG. 4, which shows a sensor circuit 42 with an amplifier 44 connected to the infrared sensor 30. The amplifier increases the magnitude of the sensor signal for easier manipulation, and also is used for determining the resistance and gain of the sensor. Because the amplifier would be necessary even without the sensor resistance and gain functions performed in accordance with the present invention, these additional

functions are provided with a minimum of additional components.

When a measurement object 45 (such as the calibration reference 36) is placed in front of the infrared sensor 30, infrared radiation from the object is received by the hot junction 34 of the sensor, producing a sensor output signal. As shown in FIG. 4, the output signal from the infrared sensor 30 is provided over a signal line 46 to the positive input terminal of the amplifier 44, while four resistors 50, 52, 54, and 56 are selectively taken into and out of the circuit 42, as described more fully below, depending on the desired circuit function. A switch 58 operates under control of a microprocessor (not shown in FIG. 4) to control the operation of the circuit and to determine the sensor resistance in the following manner.

With the switch 58 open, the resistors 54 and 56 essentially play no part in the circuit 42, and the circuit assumes an amplifying mode of operation. The circuit therefore effectively becomes that shown in FIG. 5, which is essentially a thermopile voltage amplifier circuit whose gain is set by the first two resistors 50 and 52. Thus, when the temperature of the infrared sensor 30, and in particular the temperature of the cold junction 32 (FIG. 2), is approximately equal to the temperature of the measurement object 45, the amplifier output E_o is approximately 0 volts. If the measurement object is the calibration reference 36, the output signal E_o constitutes the sensor reference signal P_b.

When the switch 58 is closed, on the other hand, the circuit 42 assumes a resistance measurement mode of operation and effectively becomes a resistance bridge circuit as shown in FIG. 6, with a V_{REF} applied voltage. Closing the switch activates the bridge circuit consisting

of the fourth resistor 56 and the infrared sensor 30 resistance on one side, and the third resistor 54 and the first resistor 50 on the other side. Under this condition, the amplifier output signal E_0 is equal to the baseline signal as seen with the switch open, plus the imbalance of the resistance bridge. As known to those skilled in the art, the amplifier output signal can be used to deduce the internal resistance of the infrared sensor. It is to be understood that other methods could also be used to determine the internal resistance, but the circuit shown makes efficient use of circuit components already present.

Thus, in operation, the resistance of the infrared sensor 30 is determined from the change in the baseline signal of the amplified output while the sensor is viewing the calibration reference. First, the amplifier output signal E_0 is measured with the resistance bridge circuit being inactive and then it is measured again with the resistance bridge circuit being active. The difference in the amplifier output signal indicates the sensor resistance and, from the FIG. 3 chart, the sensor temperature. The calibration reference need not be at the same temperature as the sensor, but the amplifier output signal difference is most easily determined if the reference object temperature and the sensor temperature are at least stable.

With reference again to FIG. 2, a microprocessor 60 controls the processing of signals in the thermometer 10 and controls operation of the switch 58 in the thermometer circuit 42. The microprocessor receives the calibration reference temperature from the thermistor 38 via a line 62 and receives the sensor output signal E_0 via a sensor output line 64. A coefficient memory 66 provides the processor with the predetermined coefficients for the various functions used by the thermometer.

Finally, the microprocessor provides output information and operator messages to the display 18 over a line 68.

The coefficients associated with the sensor temperature function and sensor gain function will vary from unit to unit, so an automated production line process is used to determine the coefficients for each infrared sensor 30. To determine the proper coefficients, the temperatures of the sensor and a calibration reference 36 are both initially brought to approximately 65°F and allowed approximately 30 seconds to stabilize. The output signal from the infrared sensor is then measured while the sensor and calibration reference both are held at this temperature. The temperature of the calibration reference is then independently raised to approximately 80°F and the output signal of the infrared sensor is again measured, and finally the temperature of the calibration reference is raised to approximately 108°F and the output signal of the infrared sensor is again measured.

Next, the temperatures of the infrared sensor 30 and the calibration reference 36 are both raised to approximately 80°F and stabilized, with the sensor output signal measured. The calibration reference's temperature is then raised to 108°F and the sensor output signal is again measured. The last step is for the temperature of the sensor and the calibration reference to be stabilized at approximately 100°F, with the sensor output signal measured. The calibration reference's temperature is then stabilized at 108°F, and the sensor output signal is again measured. These various measurements provide a table of values and characterize the coefficients in the sensor temperature quadratic equation and also characterize the coefficients in the sensor gain function. Alternatively, a table of values could be supplied in lieu of coefficients for the sensor gain function.

With reference again to FIG. 1, a flashing light 70 is provided on the thermometer body 12, to indicate when the baseline signal P_b is varying to an extent that the thermometer 10 cannot calibrate. This indicates to the operator that the thermometer has conditioned itself not to allow a temperature measurement to be taken. Some heat transfer from the patient's body can occur during measurement, so the calibration waiting time allows the sensor temperature to cool down and stabilize.

While the trigger 22 is depressed, the display 18 is updated approximately three times per second to show the present target temperature reading. Releasing the trigger displays the maximum calculated temperature that was calculated while the trigger was being depressed. This allows the operator to scan the eardrum, and more reliably obtain a temperature reading corresponding to the eardrum. This is necessary because the infrared sensor 30 receives infrared radiation not only from the eardrum, but also from the ear canal. The temperature of the eardrum is the more accurate indication of body temperature, and fortunately the temperature of almost all of the other objects within the ear will be lower than the eardrum temperature. Therefore, saving the maximum temperature reading while the infrared sensor was scanned through the ear will save and display a temperature most likely to be that of the eardrum, giving a reliable indication of the likely body temperature.

In an alternative, more simplified embodiment of the invention, the calibration reference 36 is eliminated or at least used only infrequently. In this embodiment, the target temperature, i.e., the patient's body temperature, is determined based only on the sensor's gain and the sensor's cold junction temperature, both of which are determined based solely on the measurement of the

sensor's internal resistance. Although this embodiment's accuracy will not generally be as great as that of the embodiment that utilizes the calibration reference 36 as a part of each measurement, it nevertheless can provide useful results.

The present invention has been described above in terms of a presently preferred embodiment so that an understanding of the present invention can be conveyed. There are, however, many configurations for thermometers not specifically described herein, but with which the present invention is applicable. The present invention should therefore not be seen as limited to the particular embodiment described herein, but rather, it should be understood that the present invention has wide applicability with respect to thermometers of a wide variety of configurations. Such alternate configurations can be achieved by those skilled in the art in view of the descriptions herein.

I CLAIM:

1. An infrared thermometer comprising:

an infrared sensor having a hot junction and a cold junction;

positioning means for selectively positioning the infrared sensor relative to a measurement object so that the hot junction of the sensor receives infrared radiation from the object, whereupon the sensor generates an electrical sensor output signal indicative of any difference in temperature between the measurement object and the cold junction;

sensor temperature determining means for measuring the internal resistance of the infrared sensor and for determining the temperature of the sensor based on that resistance measurement;

gain determining means for determining a sensor gain value K based on the temperature of the sensor; and

processor means for producing a measurement of the object's temperature based on the sensor output signal and the sensor gain value.

2. An infrared thermometer determining as defined in claim 1, wherein the sensor temperature determining means includes circuit means coupled to the infrared sensor, for determining the internal resistance of the sensor to produce a sensor resistance measurement that is indicative of the sensor's temperature.

3. An infrared thermometer as defined in claim 2, wherein the circuit means includes selecting means for changing the operation of the circuit means to select between an amplifying mode in which the circuit means amplifies the sensor output signal and a resistance measurement mode in which the circuit means operates as a

resistance bridge circuit to provide the sensor resistance measurement.

4. An infrared thermometer as defined in claim 3, wherein the circuit means includes a common amplifier coupled to the sensor in both the amplifying mode and the resistance measurement mode.

5. An infrared thermometer as defined in claim 3, wherein:

the infrared thermometer further includes

a movable calibration reference having a known temperature, and

reference positioning means for selectively positioning the calibration reference in a first position so that the hot junction of the sensor receives infrared radiation from the calibration reference, whereupon the output signal of the sensor comprises a sensor reference signal, and for selectively positioning the calibration reference in a second position so that the hot junction of the sensor receives infrared radiation from a target whose temperature is to be measured, whereupon the output signal of the sensor comprises a sensor target signal; and

the processor means produces a measurement of the target's temperature based on the sensor reference signal, the resistance measurement, the sensor target signal, and the known temperature of the calibration reference.

6. An infrared thermometer as defined in claim 5, wherein the thermometer further includes thermistor means, coupled to the calibration reference, for generating a reference temperature signal representing the temperature of the calibration reference.

7. An infrared thermometer as defined in claim 5, wherein the processor means produces the measurement of the target's temperature using the following target temperature formula:

$T = ([(P_t - P_b) / K] + T_r^4)^{1/4}$, where

P_t is the sensor target signal,

P_b is the sensor reference signal,

K is the sensor gain value, and

T_r is the temperature of the calibration reference.

8. An infrared thermometer as defined in claim 7, wherein the sensor gain is determined by using the following sensor gain formula:

$K = K_a * T_s + K_b$, where

K_a is a predetermined constant term,

T_s is the sensor temperature from the sensor temperature means, and

K_b is a predetermined constant term.

9. An infrared thermometer comprising:

an infrared sensor having a hot junction and a cold junction and exhibiting an internal resistance that varies with its temperature;

positioning means for selectively positioning the infrared sensor relative to a target whose temperature is to be measured, so that the sensor's hot junction receives infrared radiation from the target, whereupon the sensor generates a sensor output signal indicative of any difference in temperature between the target and the cold junction;

gain determining means for measuring the internal resistance of the infrared sensor and for determining the gain of the sensor based on that resistance measurement; and

processor means for producing a measurement of the target's temperature based on the sensor output signal and the sensor gain.

10. An infrared thermometer as defined in claim 9, wherein:

the infrared thermometer further includes a calibration reference having a known temperature and reference positioning means for selectively positioning the infrared sensor relative to the calibration reference so that the hot junction of the sensor receives infrared radiation from the calibration reference, whereupon the sensor generates a sensor reference signal; and

the processor means produces the measurement of the target's temperature based on the sensor output signal, the resistance measurement, the sensor reference signal, and the known temperature of the calibration reference.

11. An infrared thermometer as defined in claim 10, wherein the thermometer further includes thermistor means, associated with the calibration reference, for generating a reference temperature signal representing the temperature of the calibration reference.

12. An infrared thermometer as defined in claim 10, wherein the processor means produces the measurement of the target's temperature using the following target temperature formula:

$T = ([(P_t-P_b)/K] + T_r^4)^{1/4}$, where:

P_t is the sensor target signal,

P_b is the sensor reference signal,

K is the sensor gain, and

T_r is the temperature of the calibration reference.

13. An infrared thermometer as defined in claim 10, wherein the sensor gain is determined by using the following sensor gain formula:

$K = K_a * T_s + K_b$, where:

K_a is a predetermined constant term,

T_s is the sensor temperature, and

K_b is a predetermined constant term.

14. An infrared thermometer as defined in claim 9, wherein the measurement means includes:

an amplifier connected at its input terminal to the infrared sensor; and

configuration means for configuring the amplifier to operate selectively in a first mode, wherein the amplifier amplifies the sensor target signal generated by the infrared sensor, or in a second mode, wherein a known electrical current is supplied to the sensor to produce a voltage proportional to the internal resistance of the sensor and the amplifier amplifies the voltage to produce the resistance measurement.

15. An infrared thermometer as defined in claim 9, further including circuit means having a common amplifier that receives the sensor target signal and operates in a first mode in which it amplifies the signal and operates in a second mode in which it is part of a resistance bridge circuit.

16. An infrared thermometer for measuring the temperature of a target, the thermometer comprising:

a housing;

an infrared sensor having a hot junction and a cold junction, wherein the sensor exhibits an internal resistance that varies with its temperature;

a movable calibration reference within the housing;

positioning means for selectively positioning the infrared sensor so that the hot junction of the sensor receives infrared radiation from the target, whereupon the sensor generates a sensor target signal indicative of any difference in temperature between the target and the cold junction;

reference positioning means for selectively positioning the infrared sensor relative to the calibration reference so that the hot junction of the sensor receives infrared radiation substantially only from the calibration reference, whereupon the sensor generates a sensor reference signal;

thermistor means, associated with the calibration reference, for generating a reference temperature signal T_r representing the temperature of the calibration reference;

resistance means for determining the internal resistance of the infrared sensor to produce a resistance measurement;

gain determining means for determining the gain K of the infrared sensor based on the resistance measurement means for producing a measurement of the target's temperature using the following target temperature formula

$$T = ([(P_t-P_b)/K] + T_r^4)^{1/4},$$ where

P_t is the sensor target signal,

P_b is the sensor reference signal,

K is the sensor gain, and

T_r is the calibration reference temperature signal.

17. An infrared thermometer as defined in claim 16, further including circuit means having a common amplifier that receives the sensor target signal and operates in a first mode, in which it amplifies the signal, and operates in a second mode, in which it is part of a resistance bridge circuit.

18. An infrared thermometer for measuring a patient's body temperature, comprising:

an infrared sensor having a hot junction and a cold junction and further having an internal resistance that varies according to the temperature of the cold junction;

a calibration reference;

positioning means for positioning the infrared sensor relative to the calibration reference, in a calibration mode, such that the sensor produces a sensor reference signal indicative of any difference in temperature between the calibration reference and the sensor's cold junction, the positioning means further positioning the infrared sensor relative to a target on the patient, in a measurement mode, such that the sensor produces a sensor target signal indicative of any difference in temperature between the target on the patient and the sensor's cold junction;

means for determining the temperature of the calibration reference;

gain determining means for measuring the internal resistance of the infrared sensor's cold junction and for determining the gain of the sensor in accordance with that resistance measurement; and

processing means for producing a measurement of the temperature of the target of the patient based on the sensor reference signal, the sensor target signal, the calibration reference temperature determination, and the sensor gain determination.

19. A method of measuring the temperature of a target using a thermometer of the type having a housing and including an infrared sensor having a hot junction and a cold junction, the method comprising the steps of:

determining the temperature of a calibration reference located within the housing;

positioning the calibration reference relative to the infrared sensor so that the hot junction of the sensor receives infrared radiation substantially only from the calibration reference, whereupon the sensor generates a sensor reference signal indicative of any difference in temperature between the target and the cold junction of the sensor;

positioning the infrared sensor relative to the target so that the hot junction of the sensor receives infrared radiation from the target, whereupon the sensor generates a sensor target signal indicative of any difference in temperature between the target and the cold junction of the sensor;

determining the internal resistance of the infrared sensor to produce a resistance measurement;

determining the gain K of the infrared sensor based on the resistance measurement; and

producing a measurement of the target's temperature using the following target temperature formula

$T = ([(P_t-P_b)/K] + T_r^4)^{1/4}$, where

P_t is the sensor target signal,

P_b is the sensor reference signal,

K is the sensor gain, and

T_r is the temperature of the calibration reference.

20. A method of measuring temperature as defined in claim 19, further comprising the steps of:

providing a circuit that includes selecting means for changing the operation of the circuit to select between an amplifying mode and a resistance measurement mode and that includes a common amplifier coupled to the sensor in both the amplifying mode and the resistance measurement mode; and

selecting the resistance measurement mode during the step of determining the internal resistance of the sensor and selecting the amplifying mode during the

step of producing a measurement such that the circuit amplifies the sensor target signal in the amplifying mode and operates as a resistance bridge circuit to provide the sensor resistance measurement in the resistance measurement mode.

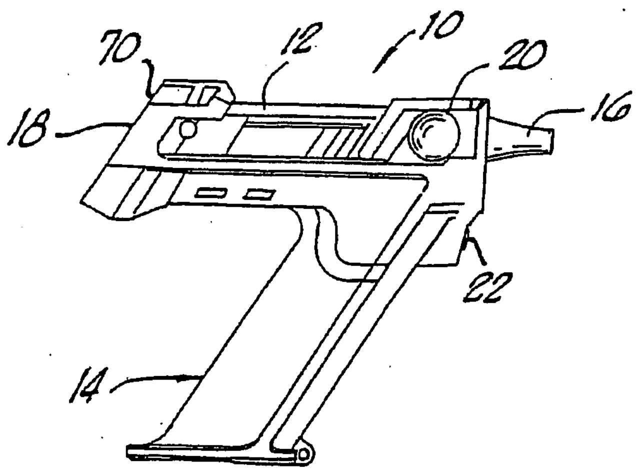
70
12
10
20
16
18
22
14

FIG. 1.

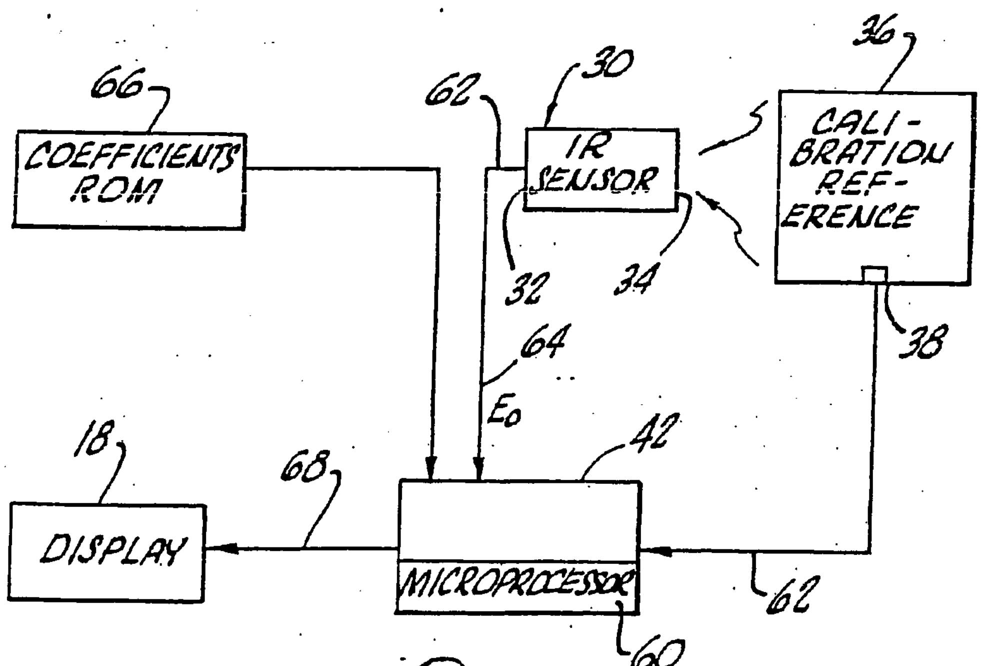
66
COEFFICIENTS ROM
62
30
IR SENSOR
36
CALI-BRATION REF-ERENCE
32
34
38
64
E_0
18
68
42
DISPLAY
MICROPROCESSOR
62
60

FIG. 2.

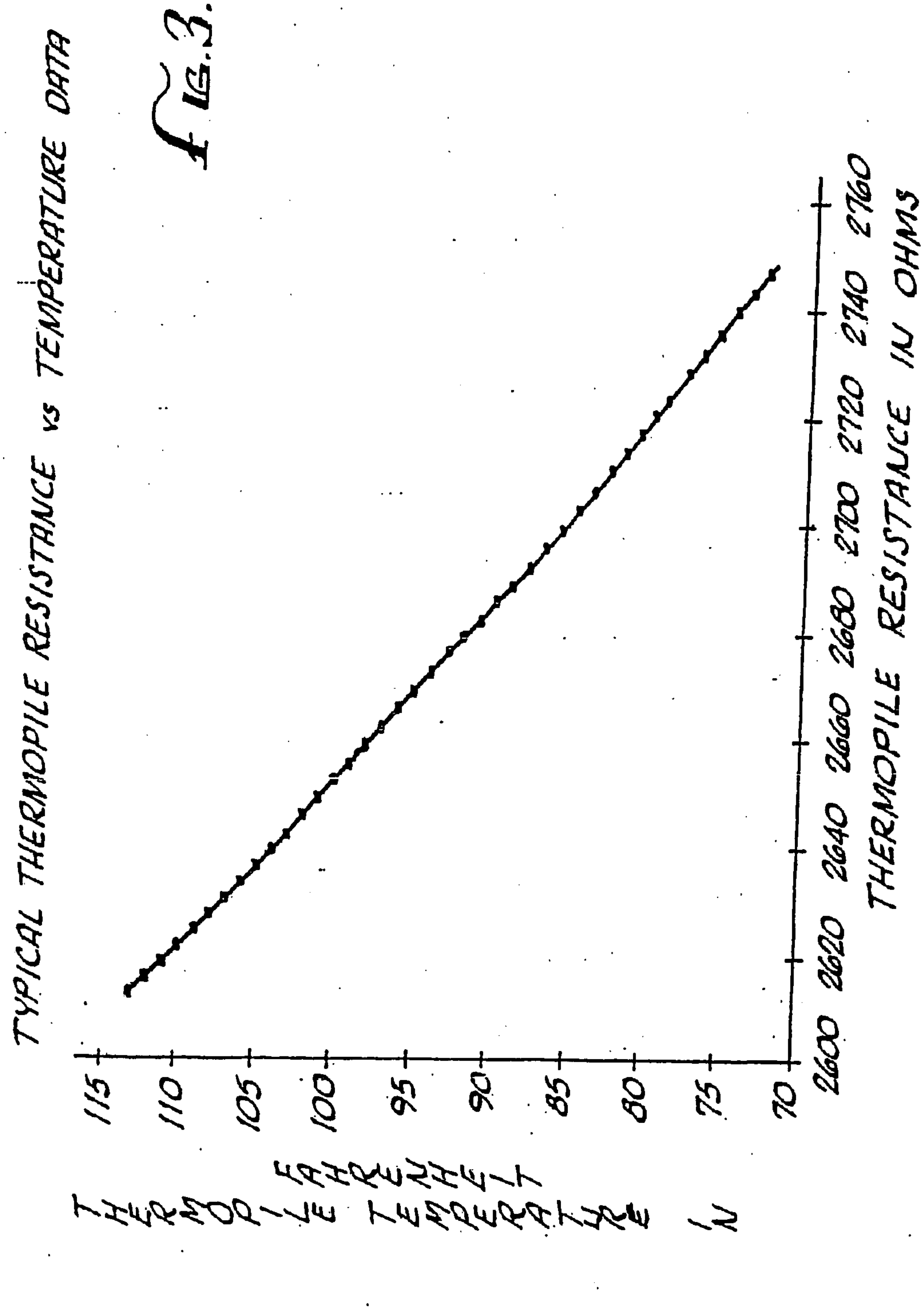
TYPICAL THERMOPILE RESISTANCE vs TEMPERATURE DATA
THERMOPILE RESISTANCE IN OHMS
2600
2620
2640
2660
2680
2700
2720
2740
2760
THERMOPILE TEMPERATURE IN FAHRENHEIT
115
110
105
100
95
90
85
80
75
70

FIG. 3.

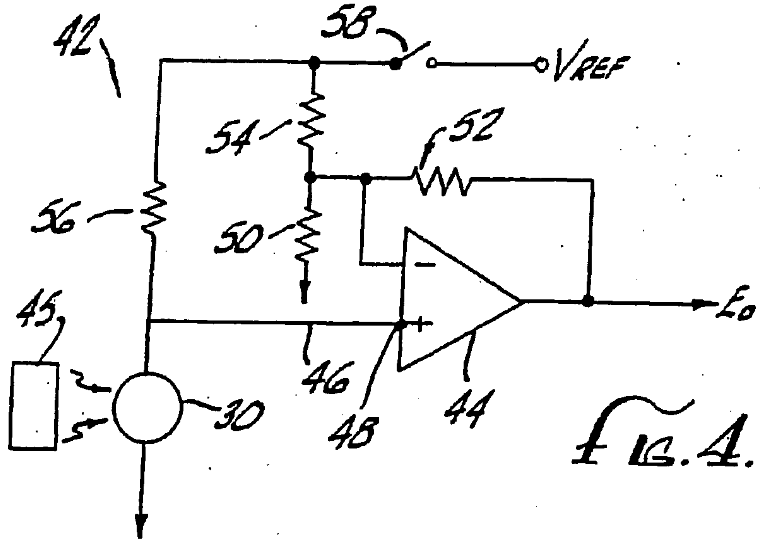

FIG. 4.

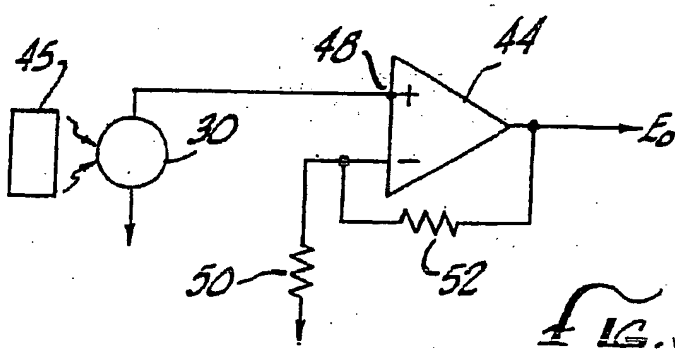

FIG. 5.

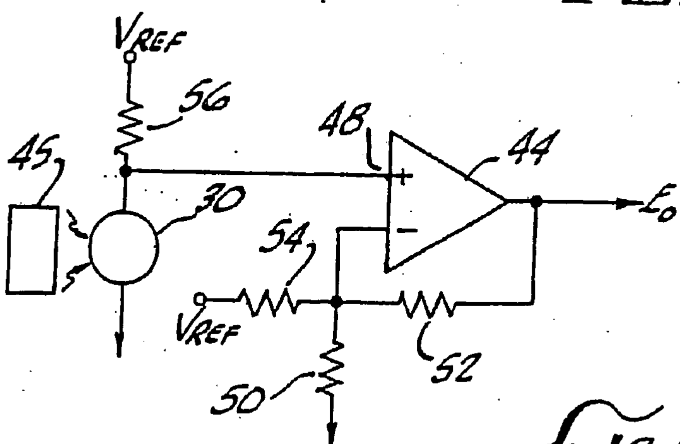

FIG. 6.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/06939

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :A61B 5/00
US CL :128/736

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 128/736 128/664; 374/121,126,129,133,181

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A, 5,012,813 (Pompei et al.) 07 May 1991 See entire reference.	1,2,9 10-13,16 18 and 19
Y	US,A, 4,993,424 (Suszynski et al.) 19 February 1991 See entire reference.	10-13,16 18,19
A	US,A, 2,871,701 (Knudsen) 03 February 1959 See Figure 1.	1,2 and 9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 SEPTEMBER 1992	[illegible]

Name and mailing address of the ISA/	Authorized officer
Commissioner of Patents and Trademarks	[signature]